AD-767 186

STATISTICAL ANALYSIS OF SHORTWAVE
FADEOUT OCCURRENCE FOR THE YEARS
1955 TO 1969

Richard G. Hendl, et al

Air Force Cambridge Research Laboratories
L. G. Hanscom Field, Massachusetts

28 June 1973

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DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
Air Force Cambridge Research Laboratories (PHS) L.G. Hanscom Field Bedford, Massachusetts 01730	Unclassified
	2b. GROUP

3. REPORT TITLE

STATISTICAL ANALYSIS OF SHORTWAVE FADEOUT
OCCURRENCE FOR THE YEARS 1955 TO 1969

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*

Richard G. Hendl, Capt, USAF
Robert A. Skrivanek

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
28 June 1973	17-20	2

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT, TASK, WORK UNIT NOS. 86660101	AFCRL-TR-73-0385
c. DOD ELEMENT 62101F	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d. DOD SUBELEMENT 681000	ERP No. 452

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, OTHER	Air Force Cambridge Research Laboratories (PHS) L.G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

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and correlated with solar flare data for the same period. Details of the
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during the early part of the period considered.

DD FORM 1473
1 NOV 65

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Solar flare						
Shortwave fadeout						

AFCRL-TR-73-0385
28 JUNE 1973
ENVIRONMENTAL RESEARCH PAPERS, NO. 452

SPACE PHYSICS LABORATORY   PROJECT 8666

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RICHARD G. HENDL, Capt, USAF
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iii

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Contents

Illustrations

/

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I. INTRODUCTION

The intent of this report is twofold: (1) to acquaint interested researchers with the results of an objective procedure to match shortwave fadeout (SWF) and solar flare reports, and (2) also to summarize the statistical properties of the SWF phenomena. Assuming anyone using the matched SWF/solar flare data will insist on knowing the procedure used in matching the data, this report contains a discussion of the matching rules and their underlying logic.

Anyone using the parts of this report that deal with the statistical behavior of SWF phenomena should carefully consider the limitations of the observational network and the effect these limitations have on the validity of the data itself. For example, during the period considered, the number of observatories was increasing every year but their geographical distribution was not uniform. The largest concentration occurred in Europe and North America. The results of these limitations can be seen in the data reported here.

2. DATA SOURCES

SWF data for the period 1955-1969 were obtained directly from the CRPL-F, Part B series (Solar and Geophysical Data), published by the Institute for Telecommunication Sciences and Aeronomy. These listings contain composite events constructed from concurrent or consecutive observations made at one or more observation sites. The reporting stations are listed, and various subjectively determined indices are provided to more completely describe the reconstructed event. The "widespread index" is an indication of the geographical extent of the SWF, while the "importance index" reflects a judgment as to the severity of the event.

Prior to September 1955, individual station reports were published. Such reports (apparently describing the same event) were combined into one composite description in order to use a consistent listing. No "widespread index" or "importance index" were assigned to these events.

Flare data used in the study discussed in this report consisted of a modified version of the flare list compiled by Fischer and Hendl (1969) [see Appendix A].

3. DEVELOPMENT OF ASSOCIATION CRITERIA

If the results from previous studies are accepted, a SWF characteristically begins 7 min after the flare begins but always before the flare reaches its maximum phase (Smith and Smith, 1963). This suggests that an adequate matching procedure need only require that the SWF begin in the interval between the beginning and maximum phases of the flare. Unfortunately, during early data gathering, frequent breaks in worldwide flare patrol and the frequent absence of the time of the maximum phase of the flare made such a matching procedure useful for only a portion of the cases. The procedure finally adopted was able to handle a number of difficulties which arose when analyzing incomplete data.

The first problem considered was the determination of a suitable interval between the begin times of both the SWF and the flare within which a match would be made. The interval selected had to be large enough to include the uncertainties in detecting the individual events but not be so large as to match two unrelated events. Cases when the SWF was observed prior to the onset of the flare had to be allowed due to minor breaks in the flare patrol and the uncertain detectability of flare beginnings.

Presumably, there are limiting time differences attained by only a small number of physically paired flares and SWF. Even if these differences were known, it would be undesirable to utilize them as matching criteria since it would increase the chances of matching events which were not physically part of the same

phenomenon. The first step, then, was to construct a "matching interval", which would pair the standard events with a high degree of confidence, and devise another procedure to handle the pairs with unusually large begin time differences.

The routine matching interval was determined by first constructing a frequency distribution (Table 1) of differences in SWF begin time and flare begin time per 5-min interval (up to ± 90 min). At large begin time differences the number of cases per 5-min interval became nearly constant so the matching interval was defined to include only those nonconstant intervals. As can be seen from Table 1,

Table 1. Frequency of SWF and Flare Matches
Per 5-Min Begin Time Difference Interval

Δt (Minutes)	< -30	≥ -30	≥ -25	≥ -20	≥ -15	≥ -10	≥ -5	≈ 0
No. Matches	2.5 per interval	39	48	69	110	208	386	910

Δt (Minutes)	≤ 5	≤ 10	≤ 15	≤ 20	≤ 25	≤ 30	> 30	
No. Matches)	510	134	69	51	48	32	30 per interval	

Note: Δt is positive (negative) when the flare begins earlier (later) than SWF.

this required that +10 min > Flare Begin Time - SWF Begin Time > -20 min, or the flare to begin either no earlier than 20 min prior to or no later than 10 min after the SWF had begun. This first criterion allowed for the minor breaks which existed in the flare patrol.

A SWF not matched with a flare by the above procedure could be grouped into four types:

(1) a SWF beginning close in time to a flare with an inexact begin time;

(2) a SWF beginning during a period of flare patrol outage;

(3) a SWF beginning more than 20 min after the beginning of the flare and continuing concurrently with the flare. This type would be characteristic of flares with a gradual rise to maximum where the actual begin time of the flare is subject to a large uncertainty;

(4) a SWF which occurred far removed from any flare.

Those unmatched SWF's occurring relatively close to the flare with inexact begin times were given further consideration. The begin time of the flare was adjusted by comparing the reported duration against the average duration for flares

of the same importance (Table 2). When the duration was shorter than average, the difference was subtracted from the begin time (unless the reported end time was also inexact, in which case one-half the difference was subtracted). For flares > Importance ? with longer than average duration, 10 min were arbitrarily subtracted from the begin time. The pair was considered matched if the adjusted time difference fell within the matching interval.

At this point any SWF beginning when no flare patrol was being conducted during the matching interval was removed from further consideration.

Table 2. Mean Flare Duration as a
Function of Flare Importance (After
Jensen and Fischer, 1967)

Flare Importance	Mean Duration (Minutes)
0	18
1	27
2	54
3	96
4	140

Those SWF's which occurred simultaneously with a flare for at least 75 percent of the SWF durations were matched with that particular flare. If more than one flare met this criterion, the one with the greatest importance was chosen. The 75 percent value was selected after subjectively examining cases matched manually. Ideally, the flare should be in progress for the entire SWF duration, but flares prematurely ended by patrol breaks required that a less stringent figure be used.

The number of matches made as a result of each criterion is shown in Table 3. The majority of matches is the result of considering the begin times of both the flare and SWF. While the total number of SWF's matched as a result of adjusting flare begin times and checking for a simultaneous occurrence is small, the SWF's were significant since their elimination would introduce a bias into the data due solely to the incompleteness of the flare reports. Since the data base being produced will ultimately be used to produce forecast techniques, it was important that all possible matches were made.

The potential matches affected by the incomplete flare patrol were reduced during the 1965-1969 period as evidenced by the fewer number of matches made by adjusting flare begin times. Additionally, unmatched SWF's occurring during

Table 3. Summary of SWF and Flare Pairs by Type of Match

	1955-64	1965-69
Total Number SWF Matched with Flares	2540	1873
Matching Interval	2300	1712
Matching Interval after Adjusting Flare Begin Time	48	6
75% Common Occurrence	192	155
Number SWF Occurring During No Hα Flare Patrol	164	19
Number SWF Unmatched	517	198
	3221	2071

periods of no flare patrol comprised only about 10 percent of the total SWF's un-matched during the latter period, compared to more than 30 percent for the earlier period. After considering the final matching criteria, which were the simultaneous occurrences of a SWF and flare, about 18 percent of the SWF's still remained un-matched. Apparently those were the result of a flare producing a SWF during a secondary maximum phase or other type of noncharacteristic sequence of events.

4. EVALUATION OF THE SWF AND FLARE MATCHING PROCEDURE

The SWF data published in the CRPL bulletin[*] contained the begin time of the flare which was considered to have caused the SWF. The flare was matched sub-jectively and represented the consideration of all available flare parameters. As a check on the validity of the present procedure, the frequency distribution of the flare and SWF begin time differences for those SWF matched in both lists were compared. The resulting histograms (see Figure 1) are essentially identical, the major difference is the approximately 30 percent in matches occurring in the AFCRL list. This difference is almost certainly due to the different flare data considered. It was concluded that the computerized matching techniques accurately reproduced the data as published.

If the technique is judged by considering the total number of SWF's paired with flares, the results are less encouraging at first glance since only 4336 SWF's out of 5249 (82.5 percent) are matched. However, upon closer inspection, it is appar-ent that most of the unmatched SWF's occur in the earlier years when the flare patrol coverage was less continuous and flare reporting less complete.
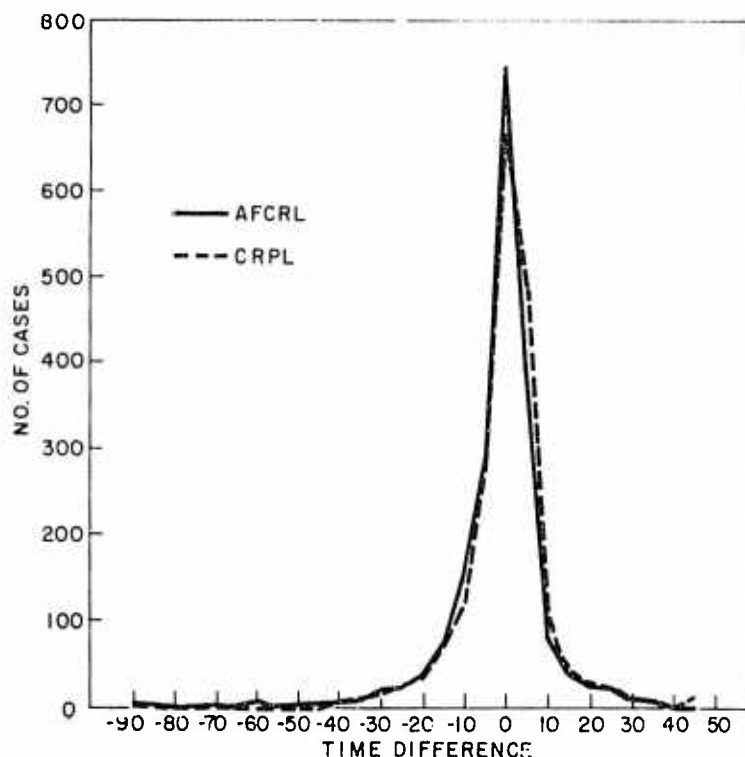
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[*]See Section 2

Figure 1. Frequency Distribution of Time Difference in Shortwave Fadeouts and Flare Start Times

The success rate for the period 1955-1964 was only 76.5 percent compared to 90.5 percent for the 1965-1969 period. Therefore, this technique appears to successfully match the majority of SWF's and Hα flares when considering only the begin times of these two data types. Other matches might be possible if additional information was taken into consideration to reconstruct the overall event.

5. RESULTS

The final listing of SWF occurrence matched with its respective solar flare appears to be reasonable in light of the limitations contained in the original data. The list is obviously more accurate for the years 1965-1969 than it is for the years 1955-1964 because of a more reliable flare patrol, and also because of a more reliable SWF patrol. The major point to be made, however, is that the objective automated procedure developed for producing this matched list does appear to work

adequately and could easily be applied to all future SWF and solar flare data. The extensive manual handling of data that is presently used to produce matched SWF and flare listing appears to be unnecessary.

Using the final matched list of SWF and solar flare occurrence, several observations were made that disclose the presence of fundamental difficulties within the SWF observing system.

In Figure 2, the total number of SWF's observed is plotted as a function of the time of occurrence in UT. Looking first at the total curve 1955-1969, it is immediately apparent that the number of SWF's that were observed, peak at approximately 1700 UT. There is no geophysical reason why more SWF's should occur at one time of day than another. The obvious explanation for this imbalance is
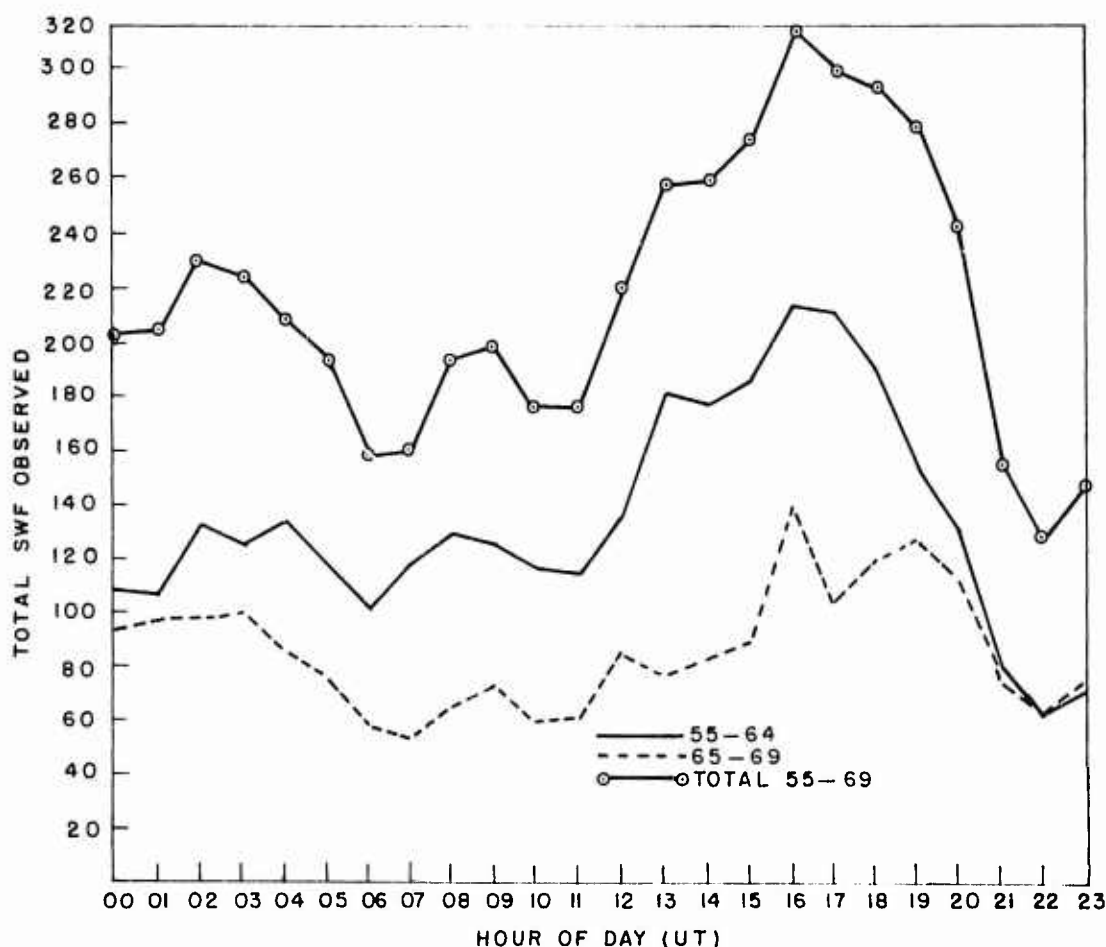

Figure 2. Total Number of Shortwave Fadeouts Observed
as a Function of Time of Day (UT)

found in the geographical distribution of SWF observatories; the largest number being in North America and Europe. As more SWF stations were added and more emphasis was placed upon gathering "good" data, the peak at 1700 hours became less pronounced. This can be seen from the two other curves on Figure 2, showing 1955-1964 data and 1965-1969 data. Figure 3, a plot of matched SWF versus time of occurrence, shows similar characteristics.
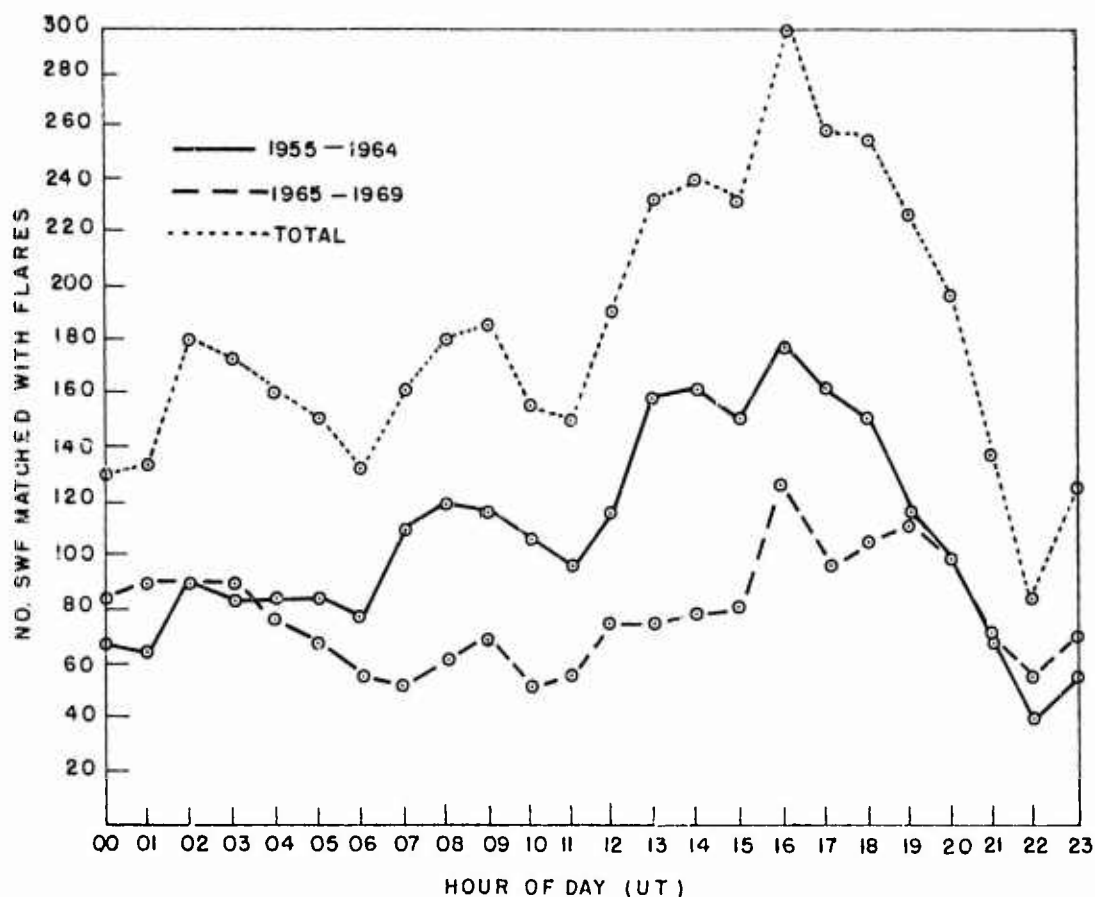

Figure 3. Number of Shortwave Fadeouts Matched with Solar Flares as a Function of Time of Day (UT)

Another example of the improvement within the observation network in recent years is shown in Figure 4. Here, the curves showing total SWF's and matched SWF's are shown for the years 1955 through 1969. Note first that the period of the curve correlates well with the Zurich sunspot number, but that the total number of SWF's in the 1969 solar maximum was very nearly the number observed
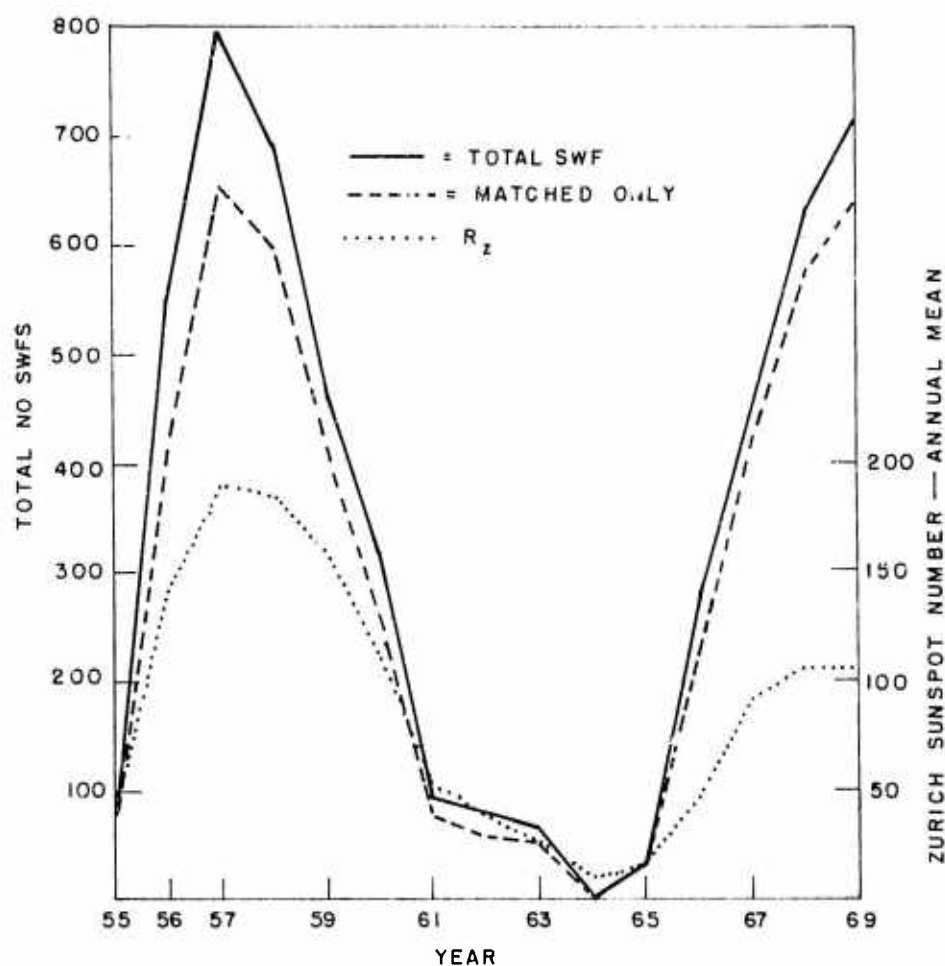
Figure 4. Total Number of Shortwave Fadeouts and Number of Matched
Shortwave Fadeouts Plotted for the Years 1955-1969. For comparison,
the Zurich sunspot number if also shown

during the 1958 solar maximum in spite of the fact that the level of solar activity
during the 1969 peak was greatly reduced from the 1958 peak. From Figure 5,
in which the total number of Importance 1, 2, and 3 SWF's is plotted against time
of occurrence (UT), another example of bias introduced into the data can be seen.
Note that the distribution of SWF's for the larger events (Importance 3) is rather
flat—indicating that, if the SWF is sufficiently large, most stations will detect it.
Smaller SWF's (Importance 1) are more easily missed and, hence, the detectabil-
ity is largely a function of the number of stations looking for the phenomena.

Another parameter used in describing SWF is the Wide Spread Index (WSI)
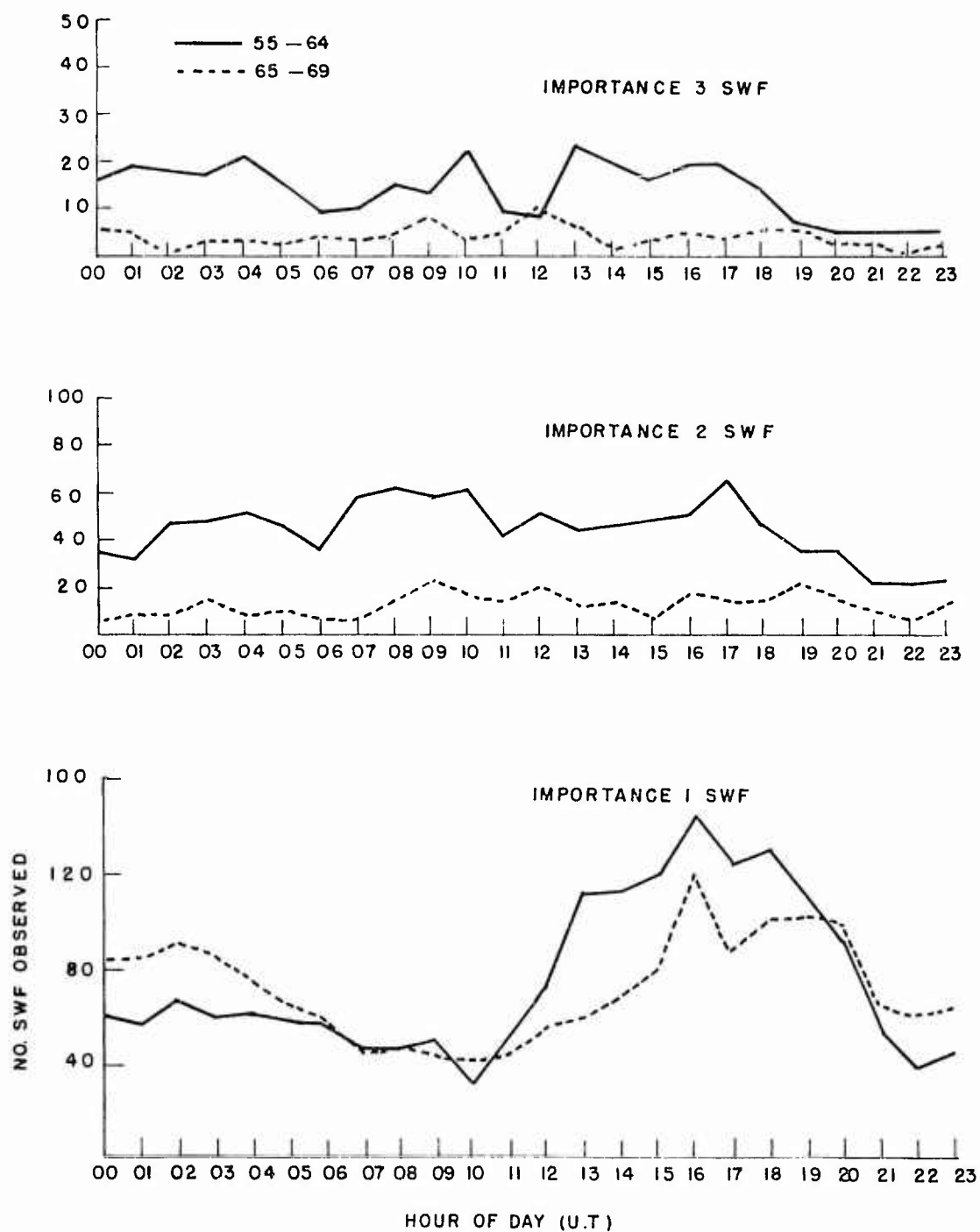which ranges from 1 to 5. This index is a subjective indication of both the

Figure 5. Number of Importance 1, 2, and 3 Shortwave Fadeouts
Plotted as a Function of Time (UT)

geographical exte it over which the SWF was observed and the degree of confidence
placed in the identification of the event. Most SWF's have a WSI of either 1 or 5
(Figure 6) which leads one to question the usefulness of this index.

It is interesting to note that in the 1955-1956 data, 74 percent of the SWF with
a SWI of 5 were Importance 3 or greater, while in 1966-1967 dat the number
dropped to only 35 percent. This again indicates an upgrading of the network,
more sensitive equipment, more experience in picking out the SWF's by the ob-
servers, and consequently attributing a higher degree of confidence in their obser-
vation and analysis. The distribution of SWF's by importance is further illustrated
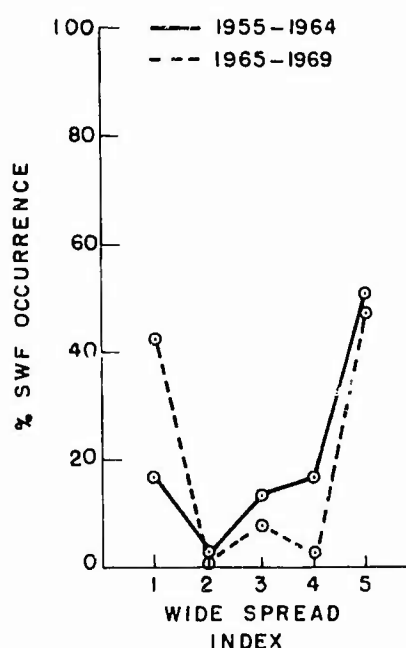in Figure 7.

Figure 6. Distribution of Short-
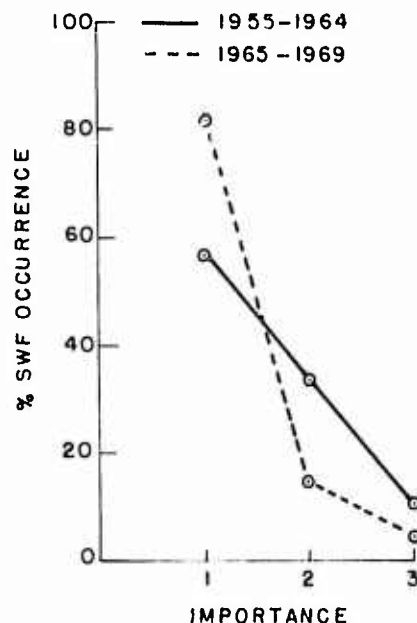wave Fadeouts as a Function of
Their Reported Widespread Index

Figure 7. Distribution of Short-
wave Fadeouts as a Function of
Their Reported Importance

Finally, in Figure 8, the number of SWF's which occurred are plotted as a
function of month of occurrence. The curves show still another curious anomaly
in which the greatest number of SWF's occurred near the spring and fall equinoxes.

In summary then, it should be repeated that the SWF data from the years
1955-1969 are inconsistent, and consequently any conclusions reached should be
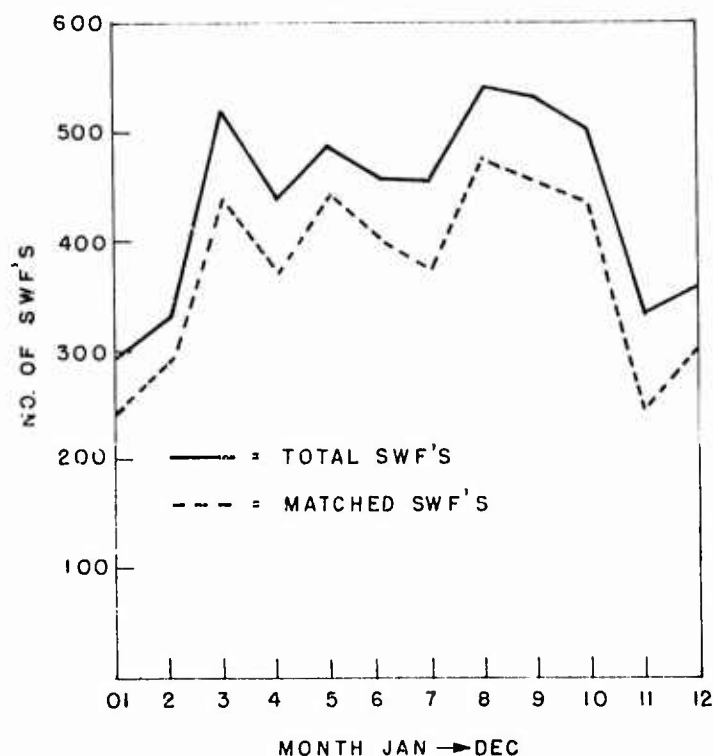very carefully considered.

12

Figure 8. Total Number of Shortwave Fadeouts Plotted as a Function of Month of Occurrence

The 1965-1969 data appears to be substantially more consistent than the earlier data, but it is not possible to determine its accuracy. It is unfortunate, however, that the SWF observing network has not thought it appropriate to introduce more modern, objective, and quantitative means of detection and measurement of these very important phenomena.

References

Fischer, H.J.E., and Hendl, R.G. (1969) Constructing Solar Flare Events by Computer, AFCRL 69-0840.

Smith, G., and Smith, E. (1963) Solar Flares, McMillan Co., N.Y.

Appendix A

Details of Flare List Modifications

The method devised to construct flare events by computer (Fischer and Hendl, 1969) was modified to produce a better estimate of the event end time.

Originally the latest end time appearing in the grouped flare reports was chosen as the event end time. This practice was responsible for producing a sizeable percentage of the cases which disagreed with the McMath-Hulbert flare list by more than 10 min (Category IV in the original report).

It appeared possible to obtain a better estimate of the event end time by a procedure similar to that which produced the event begin time. Unfortunately, agreement among several observatories when dealing with flare end times is poorer than when considering begin times. This difference in agreement makes the entire procedure impractical. A better estimate of the event end time was obtained by considering only the two latest reported end times. If the difference between the two was 60 min or greater, the earlier times became the event end time. If the 60-min interval was not exceeded, the latest reported time was used as before. The reason for not extending this practice to other earlier reported end times is similar to that already described in the discussion on the begin time procedure.

Since the logic which assigns the time of the maximum phase of the flare to the event utilizes the end time, an event with a modified end time might have a different time of maximum.